After Hubble: The Next Generation

Probing the final frontier

By RON COWEN

Call them postcards from the edge. Images from telescopes like the space-based Hubble and the giant W.M. Keck atop Hawaii's Mauna Kea are revealing what galaxies looked like several billion years ago, when the universe was only 10 percent of its current age.

Displaying a mind-boggling assortment of galaxies still in the first blush of youth, these pictures illuminate, but don't solve, the riddle of galaxy formation. Astronomers are still seeking views of the very first flickers of starlight and the birth of the first galaxies.

For that, they'll need a telescope that can probe still deeper into space and farther back in time. Indeed, for over a year now, researchers have been gathering ideas and making plans for such a device, which they expect would replace the aging Hubble in 2007.

Like Hubble, this instrument would fly above Earth, avoiding the blurring of images caused by the planet's turbulent atmosphere. To see faint objects, it must have a light-collecting area much larger than Hubble's 2.4-meter-wide primary mirror. In addition, because the expansion of the universe shifts the light emitted by distant objects to longer, or redder, wavelengths, this telescope must record images at wavelengths farther into the infrared than can reach the ground or be detected by Hubble.

In early April, just 2 months after astronauts gave Hubble a major upgrade, researchers convened at NASA's Goddard Space Flight Center in Greenbelt, Md., to discuss plans for Hubble's successor. They call the proposed instrument the Next Generation Space Telescope (NGST). Plans are still rough, and NASA Administrator Daniel S. Goldin has limited the project to $500 million—one-fourth the amount spent to build and launch Hubble.

Most designs call for a mirror 6 m to 8 m in diameter. Fully deployed, a telescope this big cannot fit inside any U.S. launch vehicle now in operation. Researchers say, however, that several foreign-made transport devices, including Russia's Proton vehicle, could be widened at relatively low cost to accommodate a 6-m telescope.

J. Roger Angel, a famed mirror maker from the University of Arizona in Tucson, has already built a prototype of a one-piece 6-m mirror. An ultrathin glass shell supported by a lightweight backing, this reflecting surface does not require perfect casting. Instead, some 3,000 tiny, adjustable screws beneath the shell would correct for sagging or other defects.

Other teams have drawn up blueprints for an 8-m telescope composed of several smaller mirrors. In one design, the mirrors would stack on top of each other for launching. Once the telescope is in orbit, they would fit together like pieces of a jigsaw puzzle. In another design, eight mirrors would surround a circular mirror like petals on a daisy; to fit inside a launch vehicle, four of the petals would fold up and the other four would fold down.

Angel cautions that although devices that can fold or stack would allow for the launch of a larger telescope, the possibility that they will fail to open may make these designs unacceptable.

Among other challenges, NGST must stay cold throughout its estimated 5-year life span. Otherwise, infrared radiation, or heat, generated by the telescope would swamp observations of the extraordinarily faint, distant celestial sources that the telescope is designed to detect. Rather than using a costly cryogenic system to keep the telescope cold, scientists hope to rely on the frigid environs of space itself. In one strategy, the telescope would be launched into a high-altitude orbit 1.5 million kilometers above Earth, where the ambient temperature is a mere 30 kelvins. To maintain this temperature inside the telescope, an umbrella-like shield must protect NGST from the sun's glare at all times.

For John C. Mather of Goddard, plans for NGST had their roots in a satellite, the Cosmic Background Explorer (COBE), that he helped design. In a triumph for cosmology, COBE found tiny temperature fluctuations in the otherwise uniform whisper of microwave radiation left over from the Big Bang. These fluctuations correspond to lumps in the sea of matter dating from about 300,000 years after the birth of the universe (SN: 5/2/92, p. 292). Over time, the tiny lumps drew together more and more material, providing the seeds for the clusters and superclusters of galaxies seen by Keck, Hubble, and myriad other telescopes.

COBE's mission ended 3 years ago, and Mather began searching for other challenges. Even before a NASA-funded panel recommended last year that the space agency build a large, infrared successor to Hubble, he and his colleagues had envisioned such an instrument. Above all, says Mather, he hopes that the new telescope will begin to fill in the murky gap between the minuscule lumps recorded by COBE and the large-scale structure that emerged less than 1 billion years later.

Moreover, "if we can see signs of the first [visible-light] things turning on, we might learn something about the dark matter," adds Mather, now an NGST project scientist. These unseen, exotic particles, which clumped together before ordinary matter did, are invoked by theorists to explain how structures such as galaxies and galaxy clusters arose relatively rapidly in the cosmos. Believed to make up 90 to 99 percent of the mass of the universe, "dark matter is presumably the stuff that makes ordinary matter move," he says.

In the April 1 Astrophysical Journal Letters, Jordi Miralda-Escudé of the University of Pennsylvania in Philadelphia and Martin J. Rees of the University of Cambridge in England calculate that NGST should detect with relative ease a key signature from that early era—supernovas marking the death of the very first massive stars.

In any stellar population, the heaviest stars burn the brightest and are the first to die. Stars between about eight and 30 times the mass of the sun end their brief lives with a bang, hurling into space their outer layers and leaving behind a collapsed, dense core. Even today, these violent outbursts may reach one-tenth the brightness of the galaxy in which they lie. In the early universe, when galaxies were smaller and less luminous, supernovas were the unquestionable champs, outshining the fledgling galaxies in which they resided, Miralda-Escudé and Rees note.

"These supernovas could be the brightest things in the [early] universe," says Robert P. Kirshner of Harvard University.

Being bright won't suffice. In order for supernovas to be easily recorded by NGST, they must also take place with reasonable frequency. Two factors suggest that these explosions, though rare, did occur often enough to make observations worthwhile, Miralda-Escudé and Rees argue. They base their assertion on two related findings by Keck astronomers over the past few years.

In the course of observing quasars, astronomers have discovered clouds of hydrogen gas that make their presence known by absorbing some of the quasar's radiation, creating a thicket of absorption lines. Recent studies with the Keck telescope have revealed that even the most distant hydrogen clouds—those that date from the early universe—also contain heavier elements, including carbon, oxygen, and nitrogen, in an abundance roughly one-hundredth that of the sun's. These intergalactic elements are highly ionized.

That presents two problems: Where did these elements come from, and what source of energy ionizes them? Ultraviolet light emitted by the very first massive stars are the most likely source of the ionizing radiation—provided there were enough such stars.

Those stars must also have produced the first heavy elements in the universe, because the Big Bang forged only hydrogen, helium, and trace amounts of beryllium and boron. Supernova explosions of these stars would have seeded the universe, including the hydrogen clouds, with the observed heavy elements—but only if the supernovas were sufficiently common.

A phenomenon brought about by the expansion of the universe should help NGST capture a glimpse of these fiery explosions. Although the brightest emissions from a supernova peter out after about 20 days, expansion stretches out that time in the viewer's frame of reference. For instance, the brilliant light of a supernova emitted at a redshift of 10—when the universe was less than 1 billion years old—would last a year. Miralda-Escudé and Rees estimate that NGST should spy, on average, one of these supernovas every year in a patch of sky one seven-hundredth the size of the full moon.

Kirshner suggests that the telescope sweep through 10 patches of sky every month, staring for about an hour at each patch. The monthly observations should be more than enough to catch a supernova, he says. "This really ought to be quite a feasible enterprise."

As an added benefit, the monthly visits would develop a body of data on each of the 10 patches that far surpasses what Hubble achieved when it stared at a single region of sky for 10 days in late 1995 (SN: 1/20/96, p. 36). In contrast to those observations, known as the Hubble Deep Field, Kirshner calls his proposed set of observations the Deep Sweep.

Abraham Loeb of Harvard and his colleagues argue that even though supernovas are the clear standouts in the early universe, clusters of the first generation of stars would have been about 1,000 times more common and should also be visible to NGST. Individual stars in this distant first generation would be too faint to detect.

"I think it's much more interesting to see a population of stars at higher redshift than the supernovas" that arose from them, says Loeb. NGST "would see not just the remnants of massive stars but the whole population."

With its large mirror and ability to detect infrared wavelengths invisible from the ground, NGST would have a unique capability to view the most distant reaches of the cosmos. Yet several astronomers at the NGST conference emphasized that the telescope could also shed light on the evolution of remote, but somewhat closer, galaxies already viewed by Hubble and by an assortment of ground-based instruments, including Keck and the Canada-France-Hawaii Telescope on Mauna Kea. These instruments provide information on the number, brightness, colors, shapes, and star formation rates of galaxies over a huge span of cosmic time, beginning a few billion years after the Big Bang and continuing to the present.

To the surprise of many astronomers, this body of data suggests that the vast majority of stars didn't begin forming until relatively late, when the cosmos was perhaps 20 percent of its current age. The peak of star birth seems to have occurred even later, when the cosmos was about half as old as it is today.

"It looks as though there really was a kind of baby boom, a burst of star formation" at that time, says Kirshner.

In that sense, says cosmologist Simon D.M. White, director of the Max Planck Institute for Astrophysics in Garching, Germany, "we have [already] seen the epoch of galaxy formation." However, he adds, current observations paint only a sketchy picture of the process.

Carlos S. Frenk of the University of Durham in England likens the current state of affairs to having a snapshot of different individuals at selected stages of development—say a baby, an infant, a teenager, and an old person—and then trying to piece together a theory of human growth. The gaps between pictures, says White, are too great to reveal a complete theory.

In addition, most of these images, as well as those to be taken by a new generation of ground-based telescopes, are recorded in visible light. For distant objects, visible light reaching Earth corresponds to radiation emitted in the ultraviolet—a set of wavelengths radiated almost entirely by the hottest, brightest, and shortest-lived stars in a galaxy. NGST's ability to examine longer wavelengths will provide a more accurate portrait of a distant galaxy, focusing on the lower-energy light emitted by the bulk of lower-mass, longer-lived stars. Such images may dramatically alter our view of galaxy evolution, says Richard S. Ellis of Cambridge.

The puzzle of galaxy formation is far from over, Ellis notes. "We want to know much more about the physical processes that are shaping the galaxies that we see around us today." Telescopes like NGST, he adds, are vital for solving that puzzle. □

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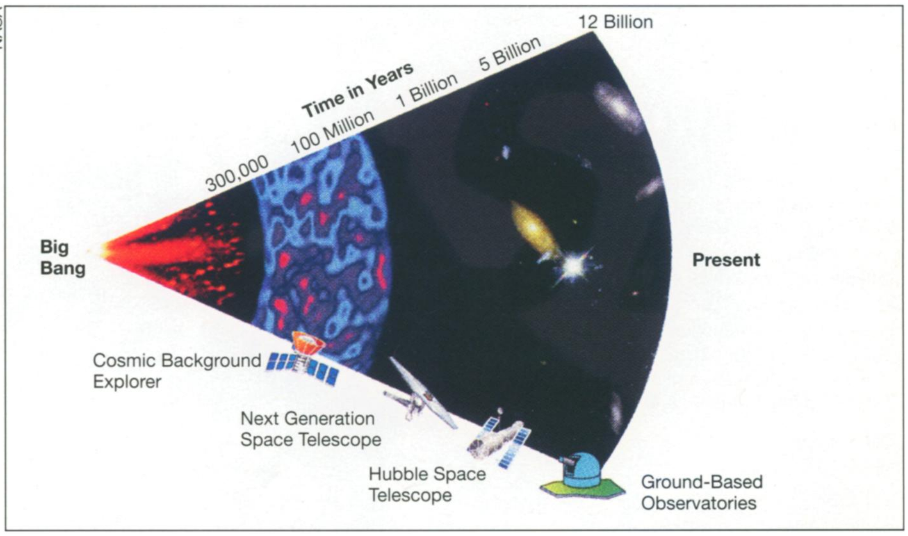

Peering deep into space and far back into time, the Next Generation Space Telescope would attempt to fill in the gap between the primordial fluctuations in density seen by the Cosmic Background Explorer and the galaxies and stars observed by the Hubble Space Telescope.